

Public Release of N-body simulation and related data by the Virgo consortium.

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ABSTRACT

We are making available on the WWW a selection of the archived data from N-body simulations carried out by the Virgo consortium and related groups. This currently includes: (i) time-slice, lightcone and cluster data from the two 10^9 -particle Hubble volume simulations described by Evrard 1998; (ii) time-slice data from simulations of 4 different cold dark matter cosmological models with 256^3 particles analysed by Jenkins et al 1998; (iii) Dark halo catalogs, merger trees and galaxy catalogs from the GIF project described by Kauffmann et al 1999. Basic software is supplied to read the data. The data can be accessed from:

<http://www.mpa-garching.mpg.de/Virgo/data-download.html>

1 INTRODUCTION

The Virgo consortium is an international collaboration whose aim is to perform large cosmological simulations of the formation of structure. We have been carrying out simulations on parallel supercomputers since 1996. In this short article we provide a brief description of datasets that we are making publicly available and we give a list of papers for refereed journals which have already made use of the data.

Over the past few years, the Virgo consortium has carried out a large number of high-resolution simulations of the clustering evolution of cold dark matter (CDM). They follow structure formation in four cosmological models: a flat model with $\Omega_0 = 0.3$ and cosmological constant, $\Lambda/3H_0^2 = 0.7$ (Λ CDM); an open model also with $\Omega_0 = 0.3$ (OCDM); and two models with $\Omega = 1$, one with the standard CDM power

spectrum (SCDM), and the other with the same power spectrum as the $\Omega_0 = 0.3$ models (τ CDM). The number of particles in the older simulations is about 17 million, with the box sizes ranging from 85 to 240 h^{-1} Mpc (where h denotes the Hubble constant in units of $100 \text{ km s}^{-1} \text{ Mpc}^{-1}$) and the particle mass from 6.86 to $22.7 \times 10^{10} h^{-1} \text{ M}_\odot$.

A variety of studies have been carried out using these data. These include investigations of the clustering statistics of the dark matter (Jenkins et al 1998, Juszkewitz, Springel & Durrer 1999); detailed analyses of the internal structure (Thomas et al 1998), velocity distributions (Colberg et al 2000) and the large-scale environment of galaxy cluster halos (Colberg et al 1999); a novel description of the topology of the dark matter distribution and a comparison with recent galaxy surveys (Springel et al 1998, Canavezes et al 1998, Canavezes & Sharpe 1998); analyses of the strong gravita-

Table 1. N-body simulation parameters. The Hubble volume data, with -hub suffix, includes lightcone outputs as well as time-slices (see Evrard 1998). The $N = 256^3$ simulations were first analysed by Jenkins et al (1998). The simulations with the -gif suffix were designed to allow galaxy formation to be followed directly and were first fully presented (including the available halo and galaxy catalogs and merger trees) by Kauffmann et al (1999).

Run	Ω_0	Λ_0	Γ	σ_8	N_{part}	$L_{\text{box}}/h^{-1}\text{Mpc}$	$m_{\text{particle}}/h^{-1}M_{\odot}$	$r_{\text{soft}}/h^{-1}\text{kpc}$
τ CDM-hub	1.0	0.0	0.21	0.60	1 000 000 000	2000.0	2.22×10^{12}	100
Λ CDM-hub	0.3	0.7	0.21	0.90	1 000 000 000	3000.0	2.25×10^{12}	100
SCDM-virgo	1.0	0.0	0.5	0.60	16 777 216	239.5	2.27×10^{11}	30
τ CDM-virgo	1.0	0.0	0.21	0.60	16 777 216	239.5	2.27×10^{11}	30
Λ CDM-virgo	0.3	0.7	0.21	0.90	16 777 216	239.5	6.86×10^{10}	30
OCDM-virgo	0.3	0.0	0.21	0.85	16 777 216	239.5	6.86×10^{10}	30
SCDM-gif	1.0	0.0	0.5	0.60	16 777 216	84.5	1.00×10^{10}	30
τ CDM-gif	1.0	0.0	0.21	0.60	16 777 216	84.5	1.00×10^{10}	30
Λ CDM-gif	0.3	0.7	0.21	0.90	16 777 216	141.3	1.40×10^{10}	30
OCDM-gif	0.3	0.0	0.21	0.85	16 777 216	141.3	1.40×10^{10}	30

tional lensing properties of clusters (Bartelmann et al 1998); ray-tracing simulations and statistical analysis of the shear fields produced by weak lensing (Reblinsky & Bartelmann 1999, Reblinsky et al 1999, Jain, Seljak & White 2000, Jain & van Waerbeke 2000, Munshi & Jain 2000a,b); studies of the Sunyaev-Zel'dovich signatures imprinted on the CMB (Diaferio, Sunyaev & Nusser 2000); tests of analytic models both for the abundance and clustering of dark halos (Sheth & Tormen 1999; Sheth, Mo & Tormen 2000) and for the bias of the galaxy population (Peacock & Smith 2000).

For the higher resolution simulations the relation between the galaxy and mass distributions has been studied both by inserting “semi-analytic” galaxy populations into the simulated dark halos at various times (Benson et al 2000a,b) and by using similar “recipes” for baryonic processes to follow the formation of galaxies directly in the simulations (the GIF project: Kauffmann et al 1999ab, Diaferio et al 1999, 2000; Somerville et al 2000). Galaxy populations constructed with the first technique have also been applied to the study of cosmic reionization (Benson et al 2000c) and in making predictions of clustering and higher order correlations which are compared to measurements from the PSCz survey (Szapudi et al 2000). The GIF galaxy, mass and halo catalogs have been used by others for studies of the statistics of the galaxy distribution (Seljak 2000, Scoccimarro et al 2000), of lensing effects due to individual galaxies (Guzik & Seljak 2000), of infall patterns onto galaxy clusters (Diaferio 1999) and for comparison with the topology of the local galaxy distribution (Schmalzing & Diaferio 2000).

Several years ago we completed the two largest N-body simulations ever attempted using a specially designed code (MacFarland et al 1999). These “Hubble volume” simulations follow a billion particles each – almost one order of magnitude more than the largest previous simulations – in the τ CDM and Λ CDM cosmologies. The simulated regions have linear, comoving dimensions of 2000-3000 h^{-1} Mpc so that, for $\Omega = 1$, the diagonal of the simulation cube extends to a redshift $z = 4.6$, nearly the size of the “observed” universe. The total mass in the $\Omega = 1$ volume is $2.2 \times 10^{21} h^{-1} M_{\odot}$, and so a cluster as rich as Coma has about 500 particles within an Abell radius. The comoving gravitational softening, $0.1 h^{-1}$ Mpc, is sufficiently small to provide reliable cluster velocity dispersions and gross assembly histories. Particles masses and softenings are similar in the Λ CDM simulation. Such large volumes require the applica-

tion of new analysis techniques that take into account the substantial light travel time across the region. In addition to storing a number of standard “snapshots” of the mass distribution, we therefore created surveys along the past light cones of hypothetical observers.

The Hubble volume simulations contain several tens of thousands of rich clusters and are so large that they can be used to investigate the behaviour of clustering diagnostics, including high order statistics, with unprecedented accuracy. The first papers analyzing Hubble volume data (Szapudi et al 2000, Colombi et al 2000) present the probability distribution of fundamental statistics such as the distribution of counts-in-cells, together with a full analysis of sampling uncertainties for estimates constructed from surveys of realistic (finite) size. Analysis of the two-point correlations of clusters is presented in Colberg et al (2000). Data from the Hubble volume simulations, together with a wide range of other Virgo data, has been used to study the mass function of dark matter halos over more than four orders of magnitude in mass (Jenkins et al 2000). Mock-galaxy catalogs constructed from the Hubble Volume simulations are used to assess the uncertainties in observational power spectrum estimates by Hoyle et al (1999).

The numerical data from all the original $N = 256^3$ Virgo simulations are now publically available, as are a variety of data products from the Hubble Volume simulations (“snapshots”, light-cone output and cluster catalogs) and from the galaxy formation modelling of the GIF project (halo catalogs, merger trees and galaxy catalogs). They may be found at: http://www.mpa-garching.mpg.de/Virgo/data_download.html

We anticipate making further data available from this site as our projects progress. Smaller data volumes can be downloaded directly over the net. Many of our datasets are too large, however, for this to be practicable. Such data can be obtained on tape after payment of a nominal fee; we impose this to avoid frivolous requests imposing unnecessary work on our archive manager. Images of many of these simulations can be down-loaded from the related websites:

<http://www.mpa-garching.mpg.de/NumCos>

<http://star-www.dur.ac.uk/~frazierp/virgo/>

<http://www.physics.lsa.umich.edu/hubble-volume/>

We would appreciate an appropriate credit if these data are used in published work. This should include the relevant reference as detailed below, as well as a mention in

the acknowledgements that the data were obtained from the Virgo consortium. The $N = 256^3$ simulations in Table 1 were first presented in Jenkins et al (1998). The original motivation for the set-up of the -gif simulations and the additional analysis involved in constructing halo catalogs, merger trees and galaxy catalogs are described in Kauffmann et al (1999a). The Hubble Volume simulations are outlined in Evrard (1998) and a detailed description is in preparation (Evrard et al 2000). We would like to keep an up-to-date record of all published papers using our data and so we would appreciate your help in notifying us by email (to C.S.Frenk@durham.ac.uk) of new papers making use of Virgo data.

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